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WORLDWIDE VHF SATELLITE SCINTILLATION/FADING TESTS

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GSFC

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

X-460-70-127

WORLDWIDE VHF SATELLITE SCINTILLATION/FADING TESTS

ATS Project

Interim report, prepared by Lowell Harman, Westinghouse Electric Corporation, on NASA contract NAS5-21129

April 1970

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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WORLDWIDE VHF SATELLITE SCINTILLATION/FADING TESTS INTERIM REPORT

INTRODUCTION

On November 11, and December 2, 9, 16, and 23, 1969, several stations throughout the world monitored the VHF telemetry signal from ATS 1, ATS 3, and ATS 5 in an attempt to characterize the effects of the ionosphere on propagation of VHF signals through the ionosphere.

These tests under the sponsorship of NASA were the first in a series to be continued during the solar-eclipse period in March 1970. The simultaneous participation of many stations permits identifying the effects of station location, satellite-elevation angle, and diurnal effects.

OBJECTIVES

The analysis consists of a survey of the strip chart recordings, with notes being made of the time, duration, magnitude and rate of propagation variations.

Objectives are:

- Compare the frequency of occurrence and magnitude of propagation variations as a function of earth-station position. This objective includes the effect of satellite elevation angle and local ionospheric conditions on the received VHF signal.
- In cases where two or more lines-of-sight intersect the F-2 ionospheric layer in close approximation, look for propagation variations caused by the same F-2 layer disturbance. This comparison of level variations between distinct rays should detect any traveling ionospheric distrubances (TID) and provide information on distrubance size. The comparison is on the basis of rate and magnitude of scintillation.
- Observe any diurnal variations, such as variations occurring repeatedly at sunrise, sunset, or local midnight.
- Note and characterize any unusual activity not accounted for by the site personnel: that is, activity which is not known to be locally caused, or caused by a passing medium or low altitude satellite.

DESCRIPTION OF TESTS

Many stations (both STADAN and university) were notified of the designated test period and asked to participate. During the test period on November 11, Mojave transmitted a signal through ATS 1 on channel 2 and Rosman through ATS 3 on channel 4. Simultaneously, ATS 3 transmitted its third harmonic generator signal and both spacecraft transmitted VHF telemetry signals. The stations monitored these signals according to their individual capability, some stations receiving signals from both spacecraft, some stations monitoring both signals or one signal from one spacecraft. Subsequent tests, because of power requirements and other testing, involved the telemetry signals of ATS 1, ATS 3, and ATS 5.

Figure 1 shows the location of the participating stations for each test period.

Table 1 lists spacecraft effective isotropic radiated power (EIRP) and signal frequencies.

Table 1
Spacecraft EIRP and Transmit Frequencies

ATS-	EIRP		Downlink Frequency (MHz)		
	Communications Channel	Telemetry Signal	Communications Channel	Telemetry PCM	Channel PFM
1	21.6 dbw	32.2 dbm	135.575	137.35	136.47
3	22.2 dbw	32.2 dbm	135.625	136.47	137.35 412.05 (clean carriers)
5	—	32.2 dbm	—	137.35	136.47

ANALYSIS

Graphical Presentation

Figures 2 through 6 summarize the results by station. The stations are arranged in ascending order of satellite-elevation angle. The figures also show the conversion factor for determining local time (T_L) from Greenwich mean

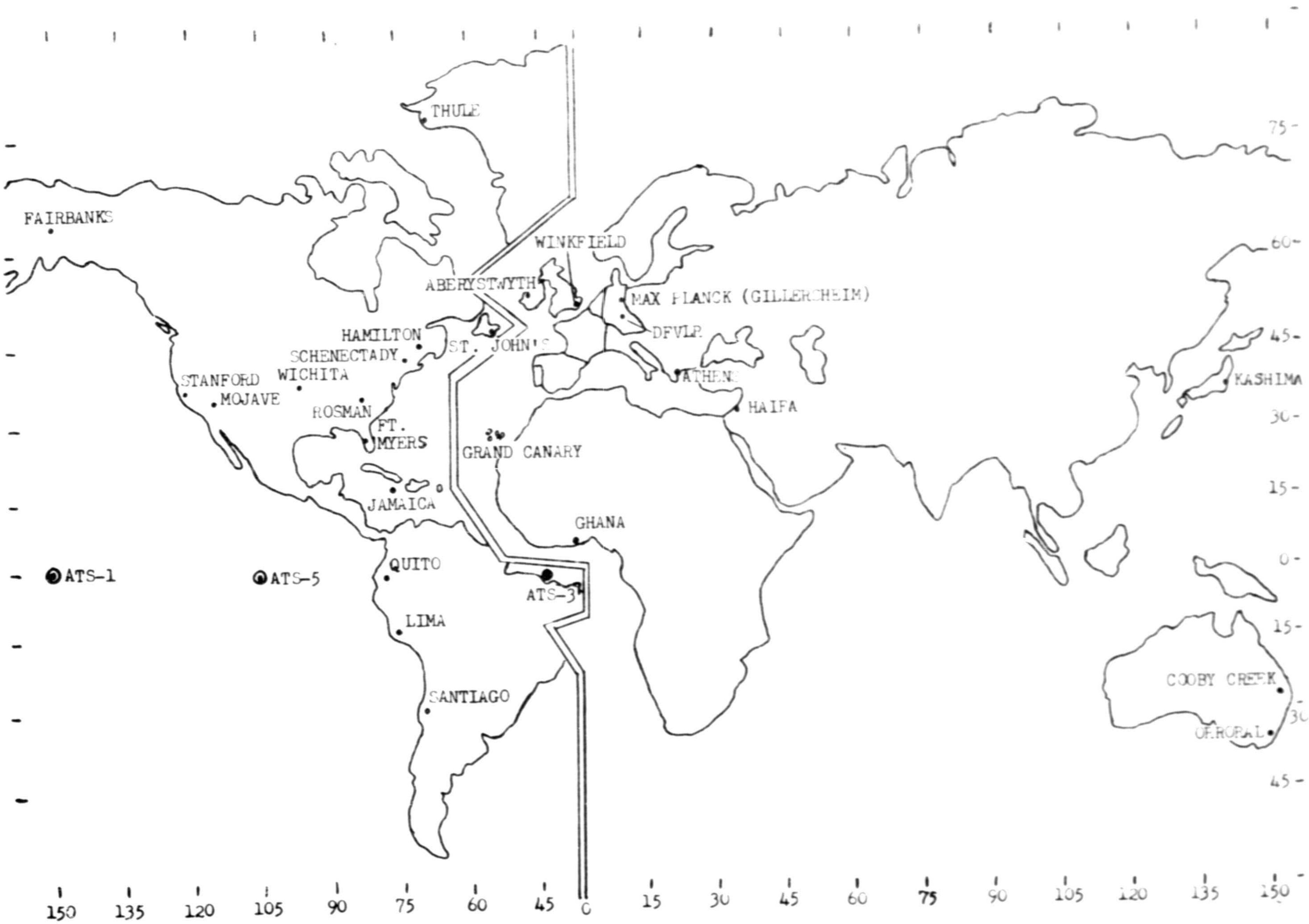

Figure 1. Location of Participating Stations

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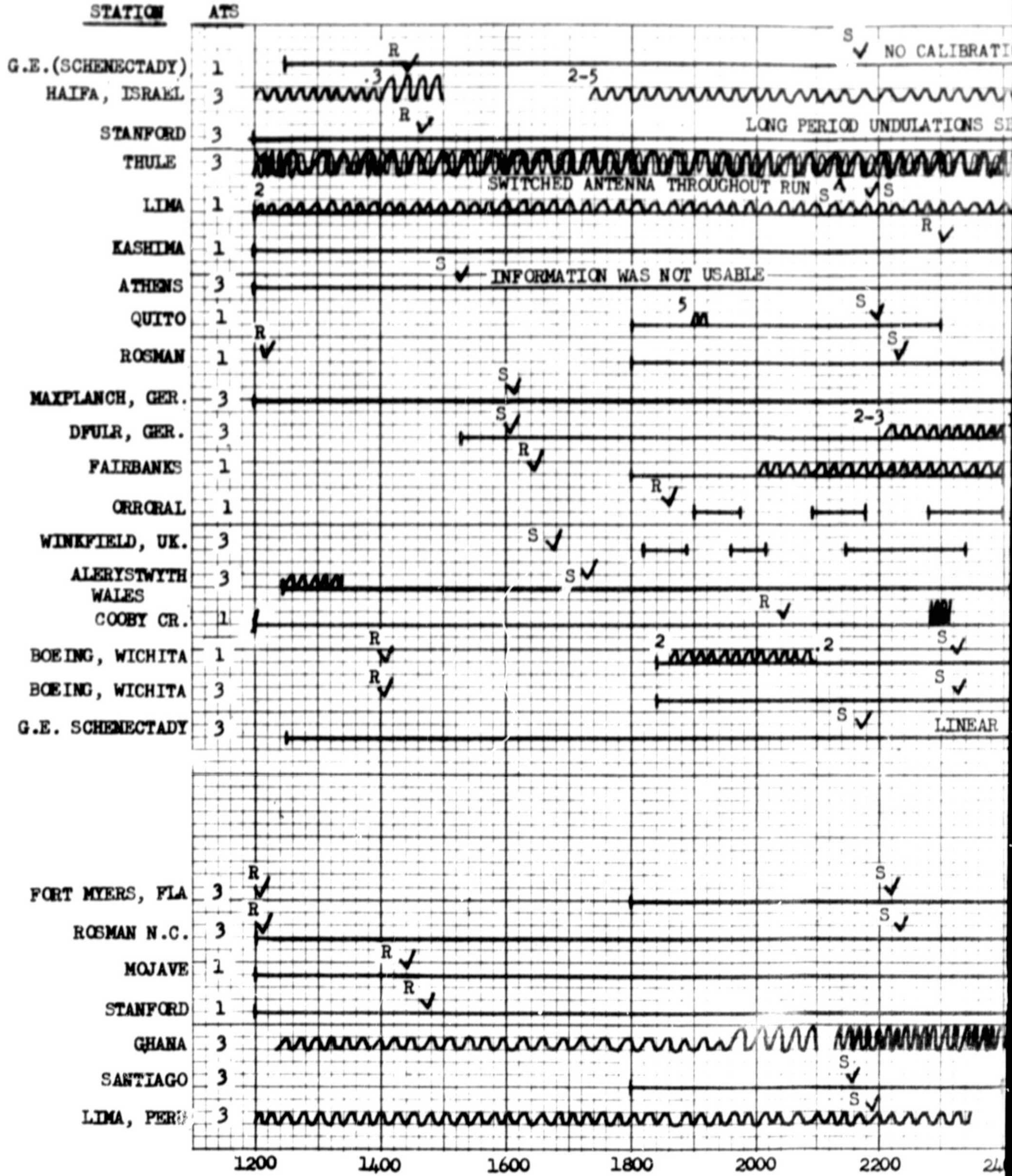

NOTES:

R✓ SUNRISE (LOCAL)
S✓ SUNSET (LOCAL

*UNDULATIONS WITH SCINTILLATIONS SUPERIMPOSED FROM

FOLDOUT FRAME /

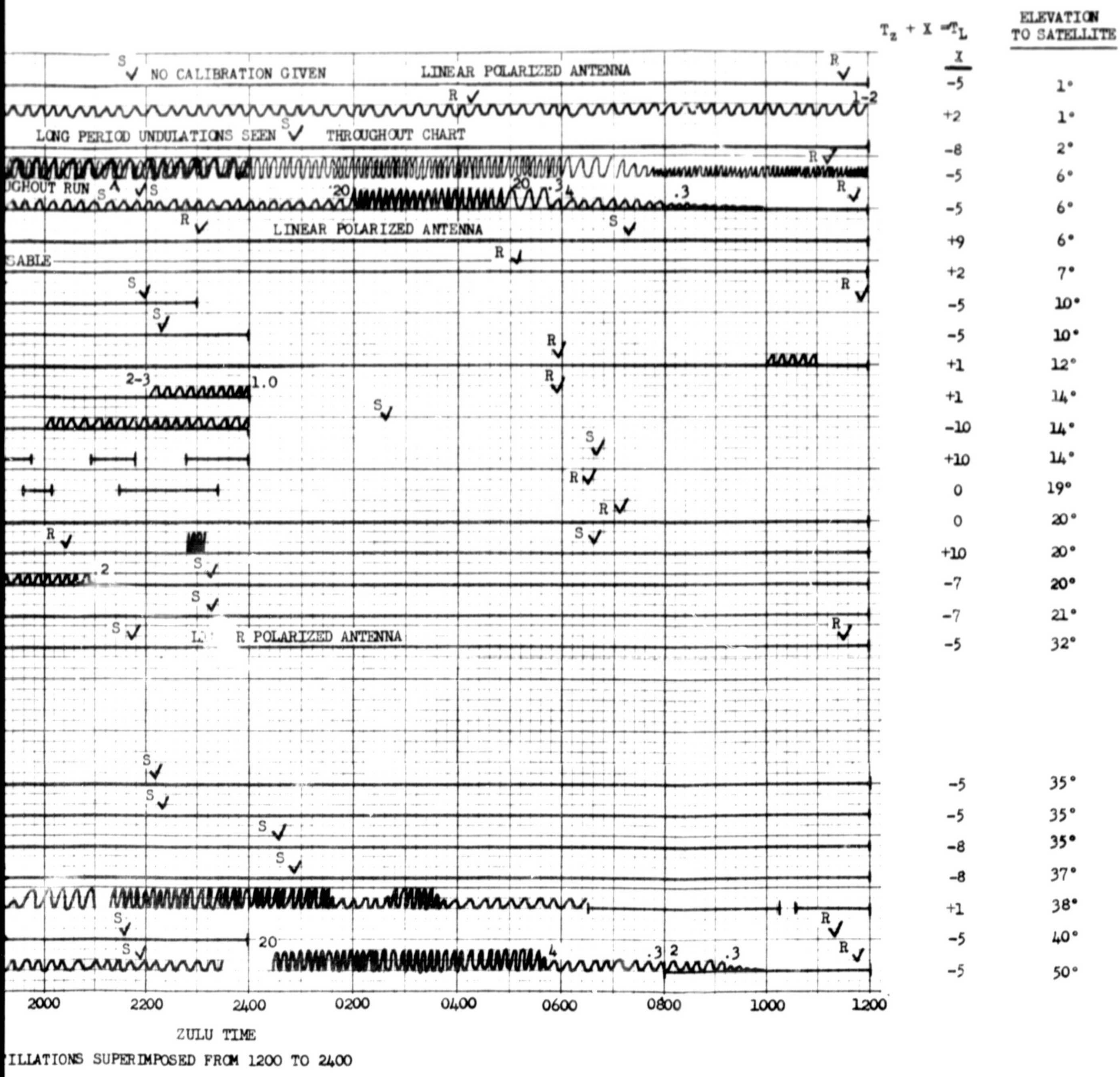

Figure 2. Propagation Test, November 11, 1969

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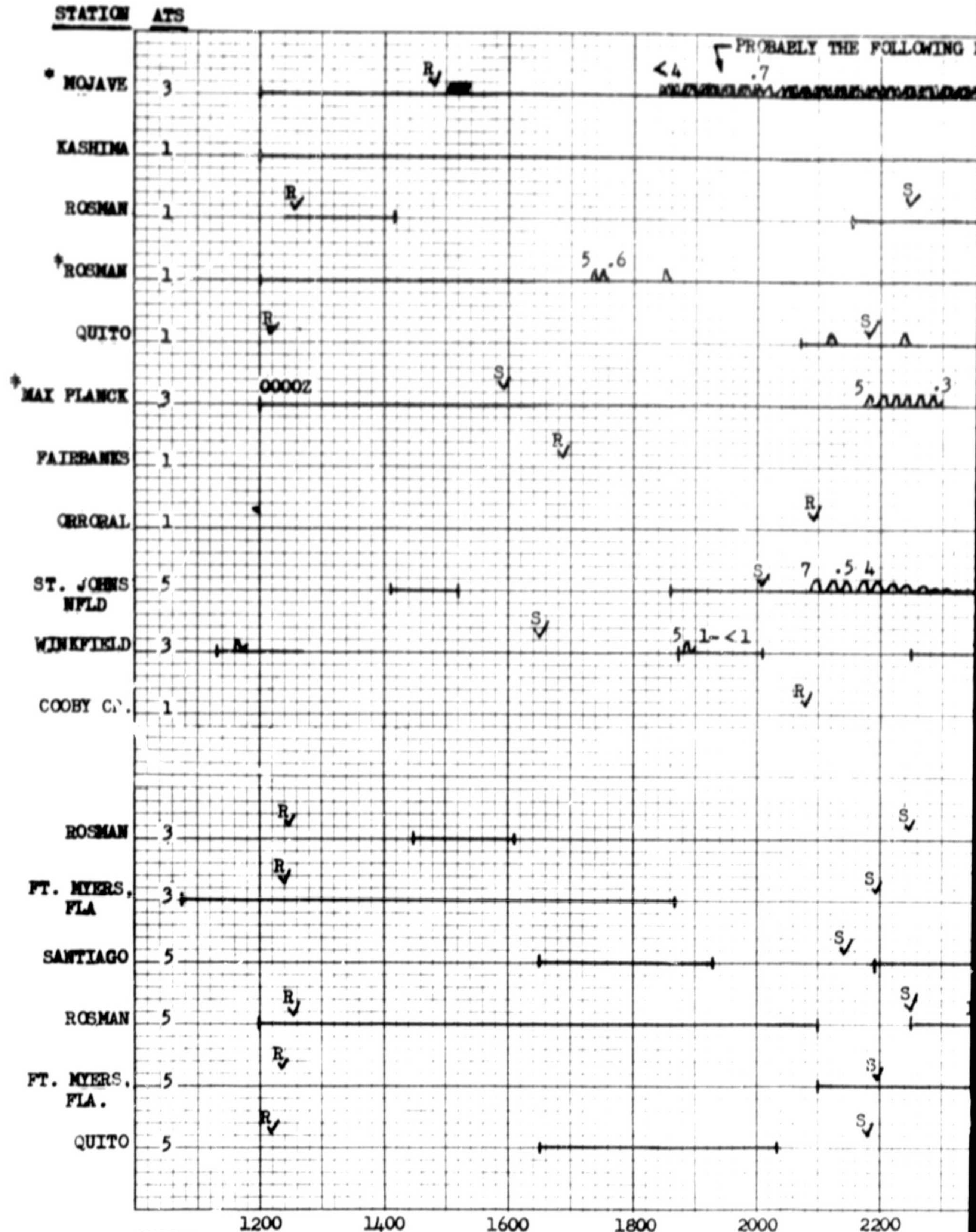

NOTES:

R✓ SUNRISE (LOCAL)
S✓ SUNSET (LOCAL)

*UNDULATIONS WITH SCINTILLATIONS SUPERIMPOSED FROM 1824Z TO 2000Z AND 2024Z TO 2355Z AND 0336

‡NOTE

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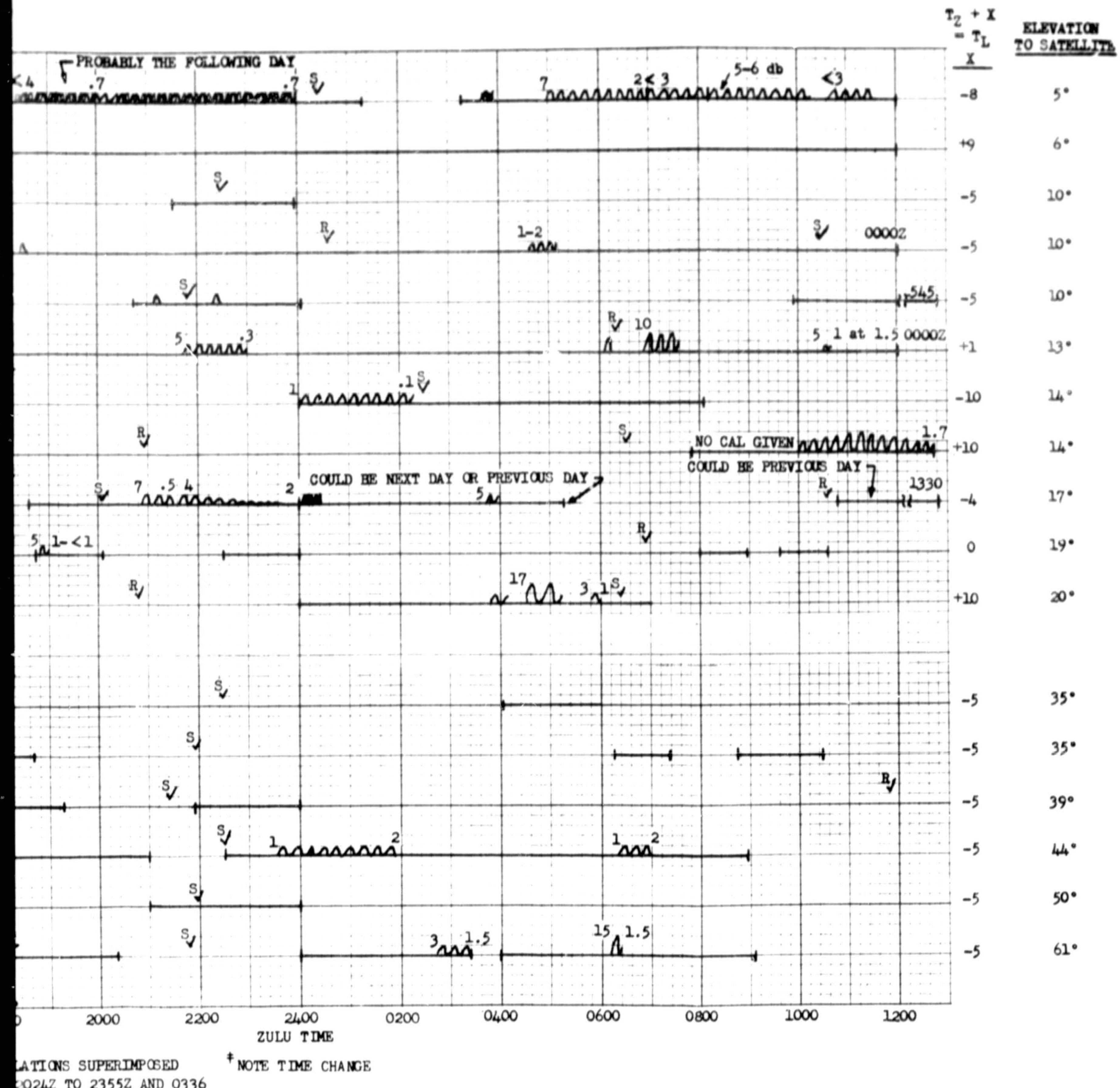

Figure 3. Propagation Test, December 2, 1969

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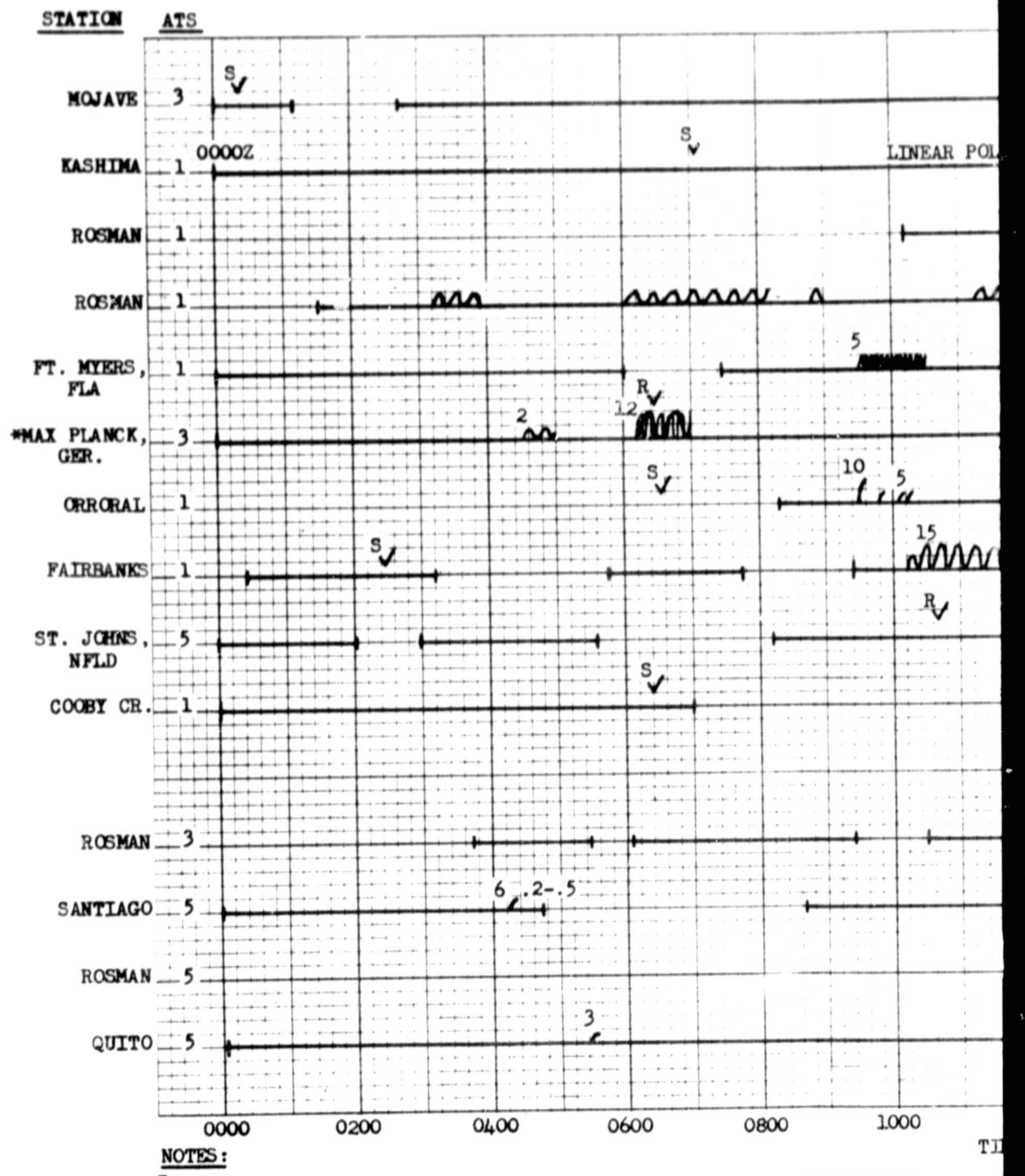

NOTES:

R✓ SUNRISE (LOCAL)

S✓ SUNSET (LOCAL)

*UNDULATIONS WITH SCINTILLATIONS SUPERIMPOSED 0612Z to 0700Z AND 1655Z TO 1712Z

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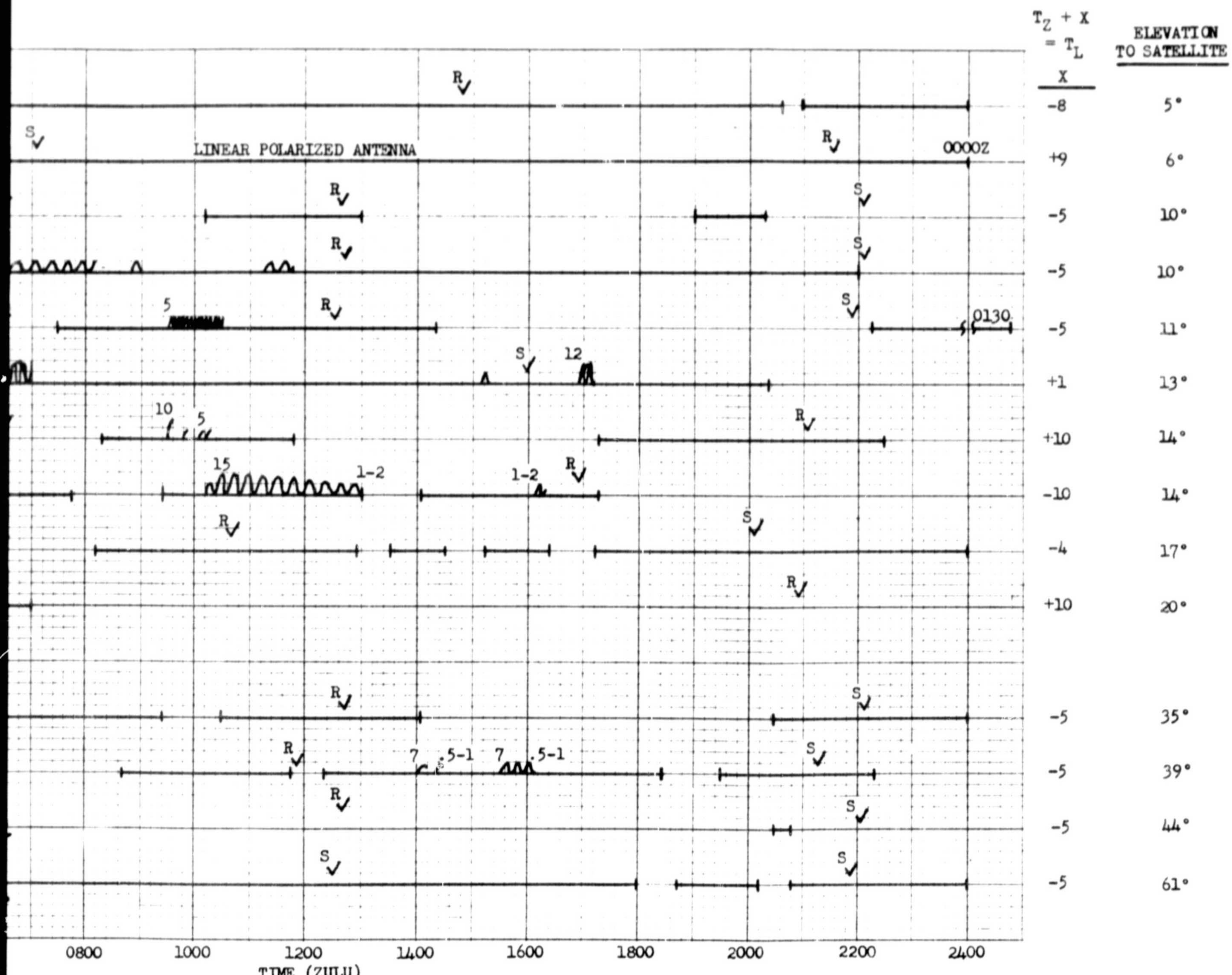

ILLATIONS SUPERIMPOSED
55Z TO 1712Z

Figure 4. Propagation Test, December 9, 1969

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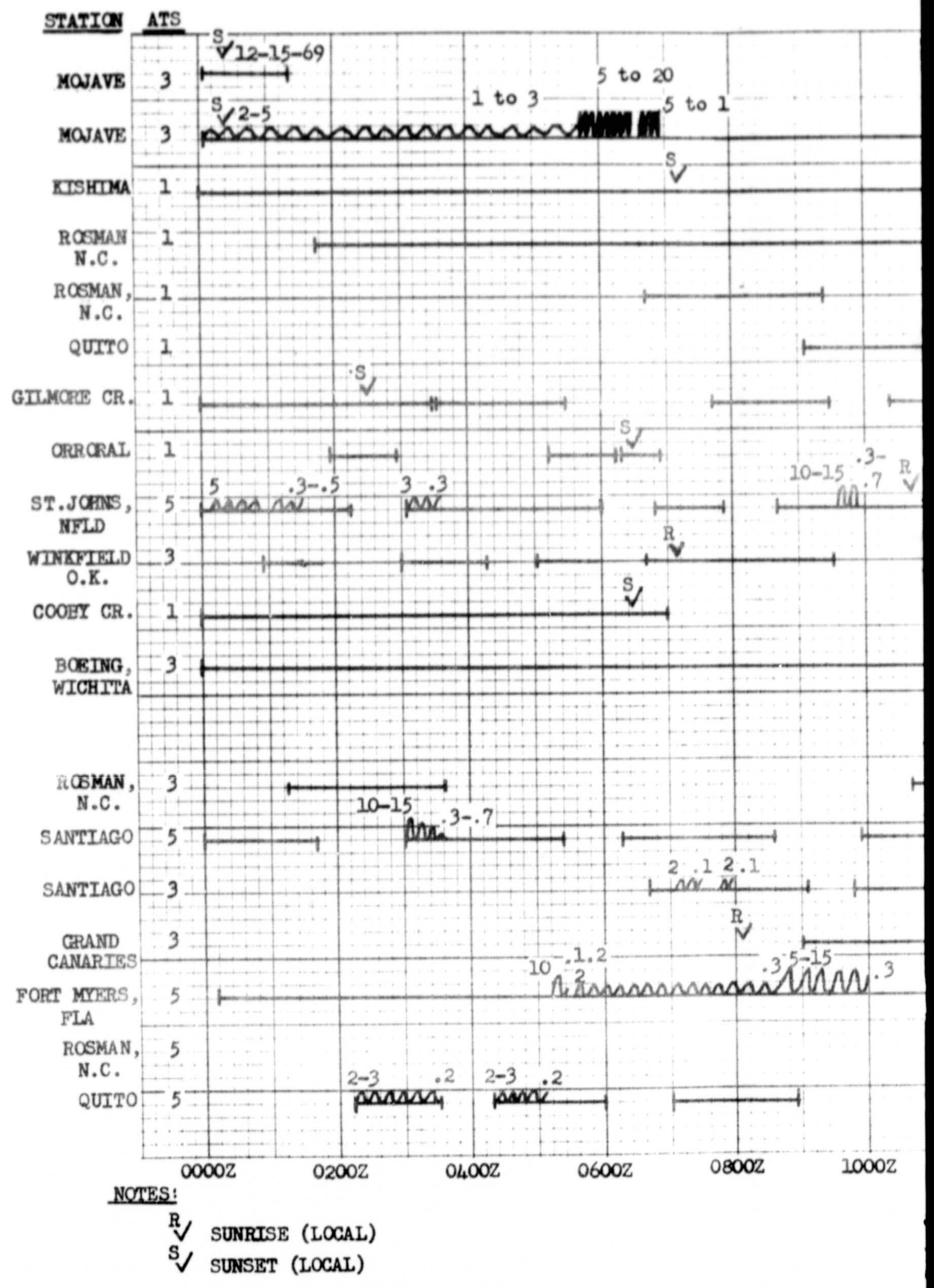

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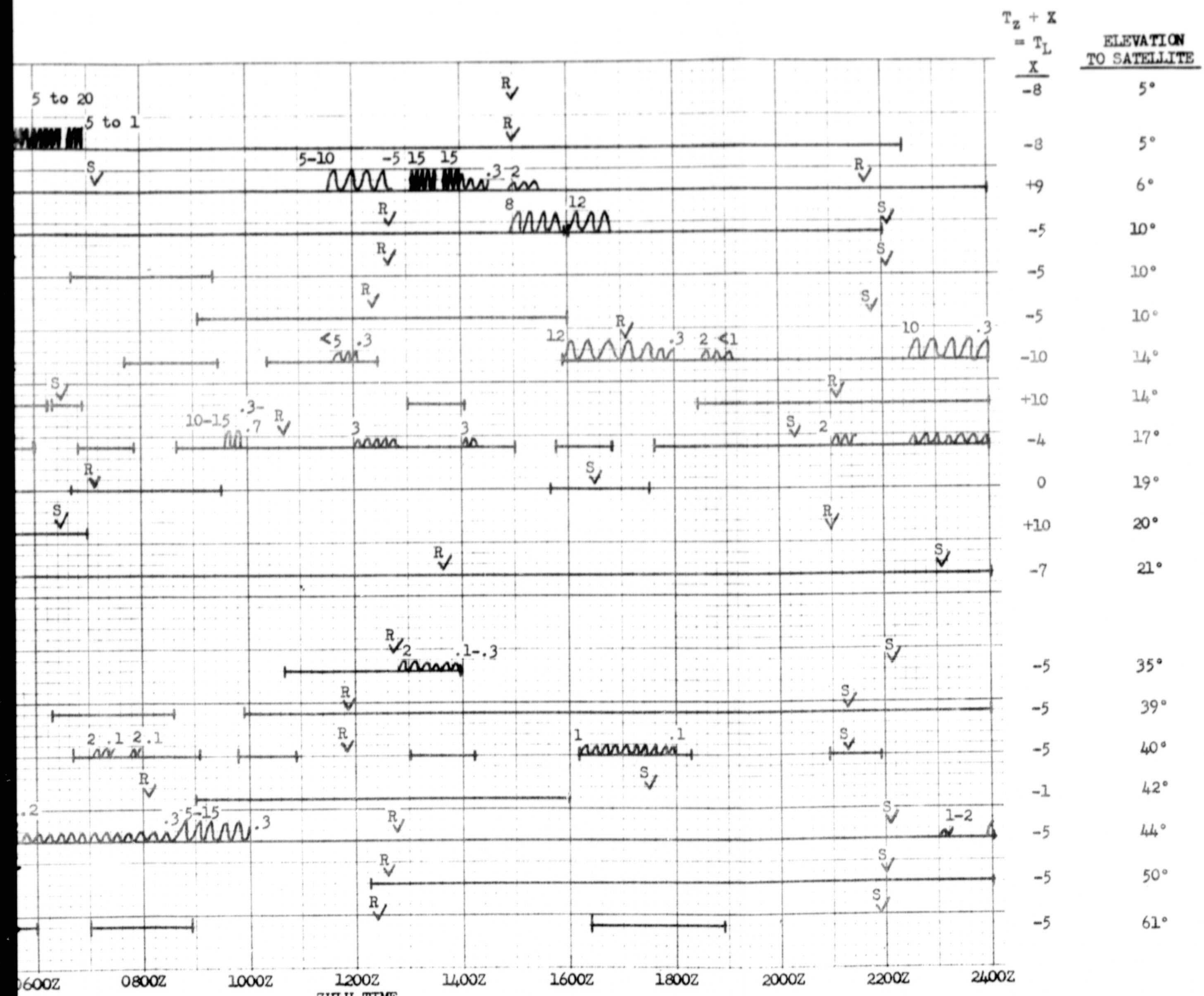

Figure 5. Propagation Test, December 16, 1969

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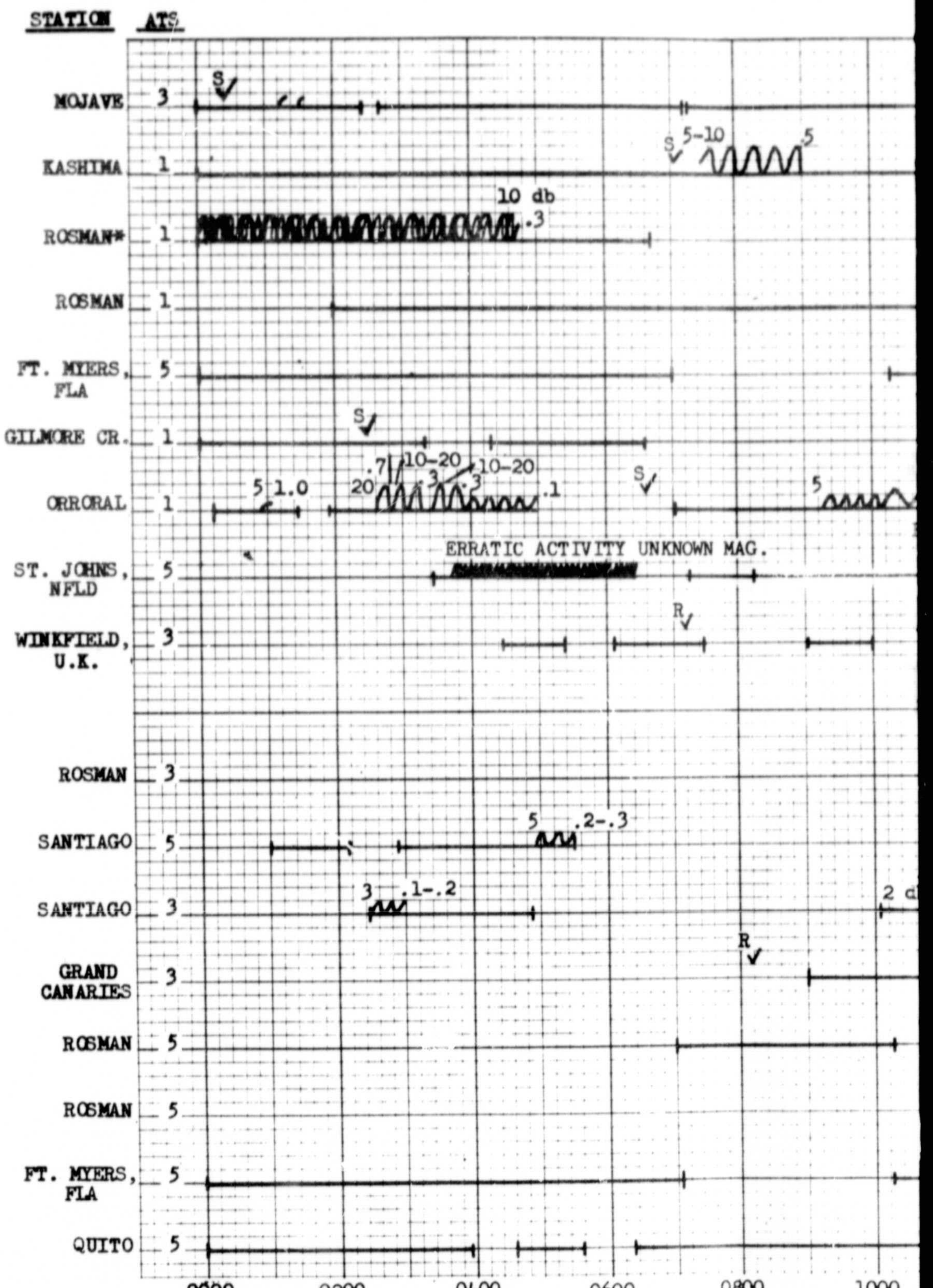

NOTES:

R√ SUNRISE (LOCAL)

S√ SUNSET (LOCAL)

* UNDULATIONS WITH SCINTILLATIONS SUPER IMPOSED FROM 0002 to 0440Z

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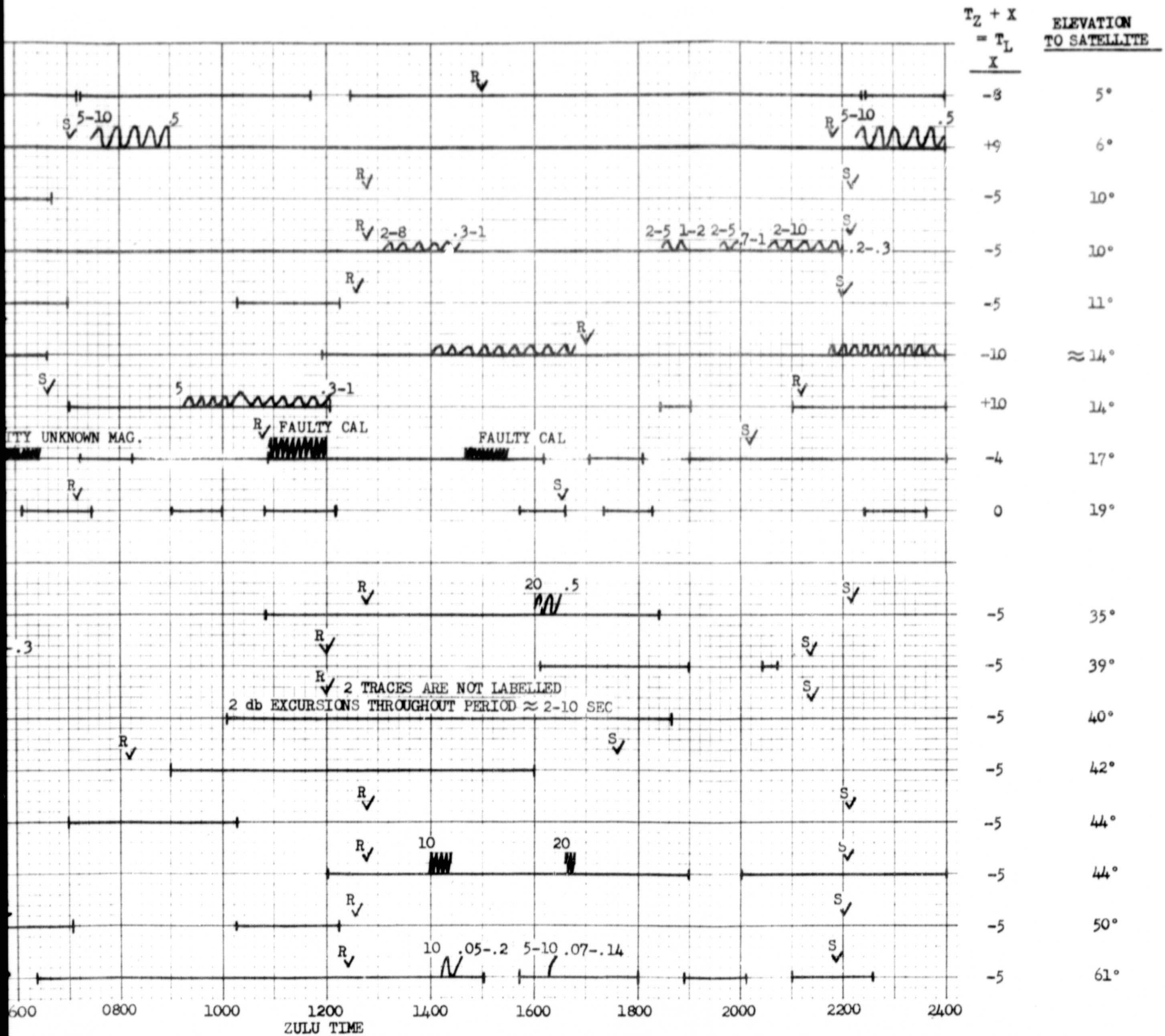

TH SCINTILLATIONS SUPER
002 to 0440Z

Figure 6. Propagation Test, December 23, 1969

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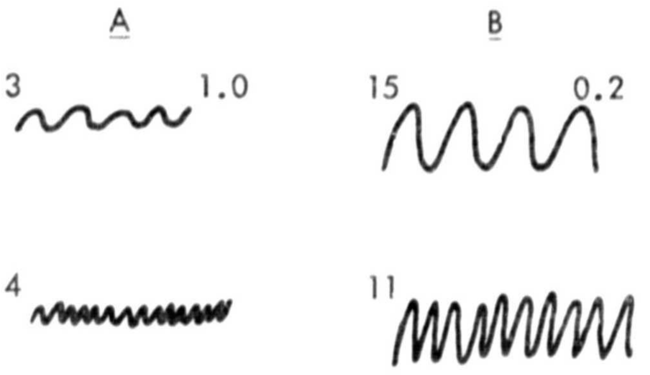
time (T_Z), as well as the station-elevation angle to each satellite. The following sketch indicates the significance of the notations in the summary charts.

Examples



Legend

A. Slow scintillations of average magnitude 3 db peak-to-peak; average period 1.0 min

B. Slow scintillations of average magnitude 15 db peak-to-peak; average period, 0.2 min

A. Rapid scintillations of average magnitude 4 db peak-to-peak

B. Rapid scintillations of average magnitude 11 db peak-to-peak

In the absence of magnitude notations, the magnitude in general is in the range greater than 7 db peak-to-peak for Example B, and less than 7 db peak-to-peak for Example A. A hyphenated numeric indicates the range of scintillation or period.

Activity Versus Station Location

Figures 2 and 3 show the high incidence of slow scintillations with satellite-elevation angles of 6 degrees or less, although this type of activity is neither peculiar to low-elevation angle stations nor does it occur at all times at these stations. Mojave, for example, with an approximate elevation angle of 5 degrees, was without activity during the December 23 test (Figure 6); Rosman, with an elevation angle of 45 degrees to ATS 5, recorded an extended period of slow scintillations during the December 16 test (Figure 5), although no activity occurred on the concurrent ATS 1 trace at Rosman (10-degree elevation angle). At low elevation angles, the probability of occurrence of slow scintillations is apparently greater than at high elevation angles.

The November 11 test graph (Figure 2) also shows a great amount of both slow and rapid scintillation activity from Thule (auroral), Lima, and Ghana (geomagnetic equator). Lima, which monitored both ATS 1 and ATS 3 on November 11, found similar high-level activity on each trace, as did Ghana. At both Lima

and Ghana, however, the rapid scintillations did not appear superimposed on slow scintillations, as at Thule, but gradual transitions between rapid and slow scintillations occurred instead.

Records from Quito (11° N geomagnetic latitude) and Santiago (-22° S geomagnetic latitude), the stations next closest to the geomagnetic equator, showed very little activity through all the tests. These results would seem to indicate a sudden increase in activity as the geomagnetic equator is approached; however, results of earlier tests[1] performed between the aircraft carrier U. S. S. Hornet and the Mojave station during Apollo 11 splashdown contradict this conclusion. During this period, the Hornet was in mid-Pacific, at approximately 9° N geomagnetic latitude and 165°W longitude, a latitude corresponding to that of Quito. The propagation data from the Hornet show extended periods of very high-magnitude scintillations. Although the Hornet data and Quito data were taken some 6 months apart, the sunspot and geomagnetic activity were nearly identical during these days.

Data Comparisons

Intersection of the F-2 layer by two lines-of-sight in relatively close approximation offered an opportunity to compare the data and to look for correlations between close ray crossings in the F-2 layer. Table 2 lists the dates, stations, and approximate distances between ray crossings.

No positive correlations appeared between the indicated recordings; those from Lima, however, showed slight slow scintillations from the start of the test until, on ATS 3, 20-db scintillations started about 2.5 hours after apparent sunset, and on the ATS 1 signal about 4 hours after apparent sunset. Both signals decrease in magnitude at local 1 a.m. and gradually fade out 4 hours later.

Data from other nearby ray crossings are necessary to detect traveling ionospheric disturbances and disturbance size. In general, three factors have impeded this effort: (1) F-2 layer ray crossings for the participating stations did not permit it; (2) too many gaps in the data; and (3) lack of scintillations in the data. This topic, however, is already covered in the literature.[2, 3, 4]

Diurnal Effects

As the November 11 test indicates for Lima and Ghana, scintillations occur at the geomagnetic equatorial stations before and after local midnight, as they did on the previously referenced Hornet tests in July. No other diurnal effects appeared.

Table 2
Shortest Distances Between F-2 Layer Line-of-Sight Intersections
(ray crossings)

Stations	ATS Number	Date	Figure Reference	Approximate Distance Between Indicated Ray Crossings in the F-2 Layer (miles)
Stanford Stanford	1 3	Nov. 11	2	1295
DFVLR, Germany Max Planck, Germany	3 3	Nov. 11	2	190
Stanford Mojave	1 1	Nov. 11	2	305
Rosman Rosman	1 3	Nov. 11	2	111
Orroral, Aust. Cooby Creek, Aust.	1 1	Nov. 11 Dec. 2 Dec. 9 Dec. 16	2 3 4 5	630
Lima, Peru Lima, Peru	1 3	Nov. 11	2	1156

At first glance, the onset of activity on ATS 1 and ATS 3 from Lima (Figure 2) appears possibly to be related to sunset, but scintillations occurred 1.5 hours apart; whereas, assuming the same ionospheric layer is responsible for the beginning of both activities, the time difference between the onset of activity on ATS 3 and ATS 1 would have been approximately 1 hour. No definite correlations with sunrise and sunset appear. The activity graphs indicate times of apparent sunrise and sunset.

Miscellaneous Observations

The December test results revealed that, when slow scintillations occurred at other than a low satellite-elevation angle, they often were not sinusoidal, but

sometimes peaked on the negative side. This appeared on the results from the following stations:

- St. John's, Newfoundland (17-degree look angle)
- Gilmore Creek, Alaska (14-degree look angle)
- Quito, Ecuador (61-degree look angle)
- Rosman, N. C. (44-degree look angle)

The St. John's data did not represent true scintillation activity, as discussed later. Future tests will reveal the extent to which these phenomena occur, and their effect on communications.

The difference between the activity at Thule and at Lima is worthy of note. At both stations, slow and rapid scintillations occur. However, the records from Thule indicate that the two perturbations arise from independent sources and occur simultaneously, resulting in greater excursions when the two perturbing forces are in phase. At Lima, the two effects do not occur simultaneously, but appear to come from the same source, in that rapid scintillations decrease in rate to become slow scintillations, and vice versa (Figures 7 and 8).

The record for St. John's, Newfoundland, on December 16 shows unusual behavior: In this trace, for part of the test duration, slow scintillations deflected the trace to the negative side only, not going positive, as in true scintillation activity. This event did not occur on any of the other traces. St. John's nominal received-signal level is -140 dbm; this phenomenon probably reflects local (perhaps equipment) conditions during the test.

CONCLUSIONS

The conclusions reported here result from analysis of the strip charts of ATS VHF received-signal level recorded on Zulu days November 11 and December 2, 9, 16, and 23, 1969, at the sites shown in Figure 1.

Figures 2 through 6, arranged in order of ascending satellite-elevation angle, constitute a graphic summary of the results. Scintillations occur most frequently at Thule (auroral), Lima, and Ghana (geomagnetic equatorial), and at stations with low satellite-elevation angles, such as Haifa, Mojave on ATS 3, and Stanford on ATS 3. The data from Thule, Lima, and Ghana show extended periods of high-level scintillations; these regions present the most serious problem to transionospheric VHF communications.

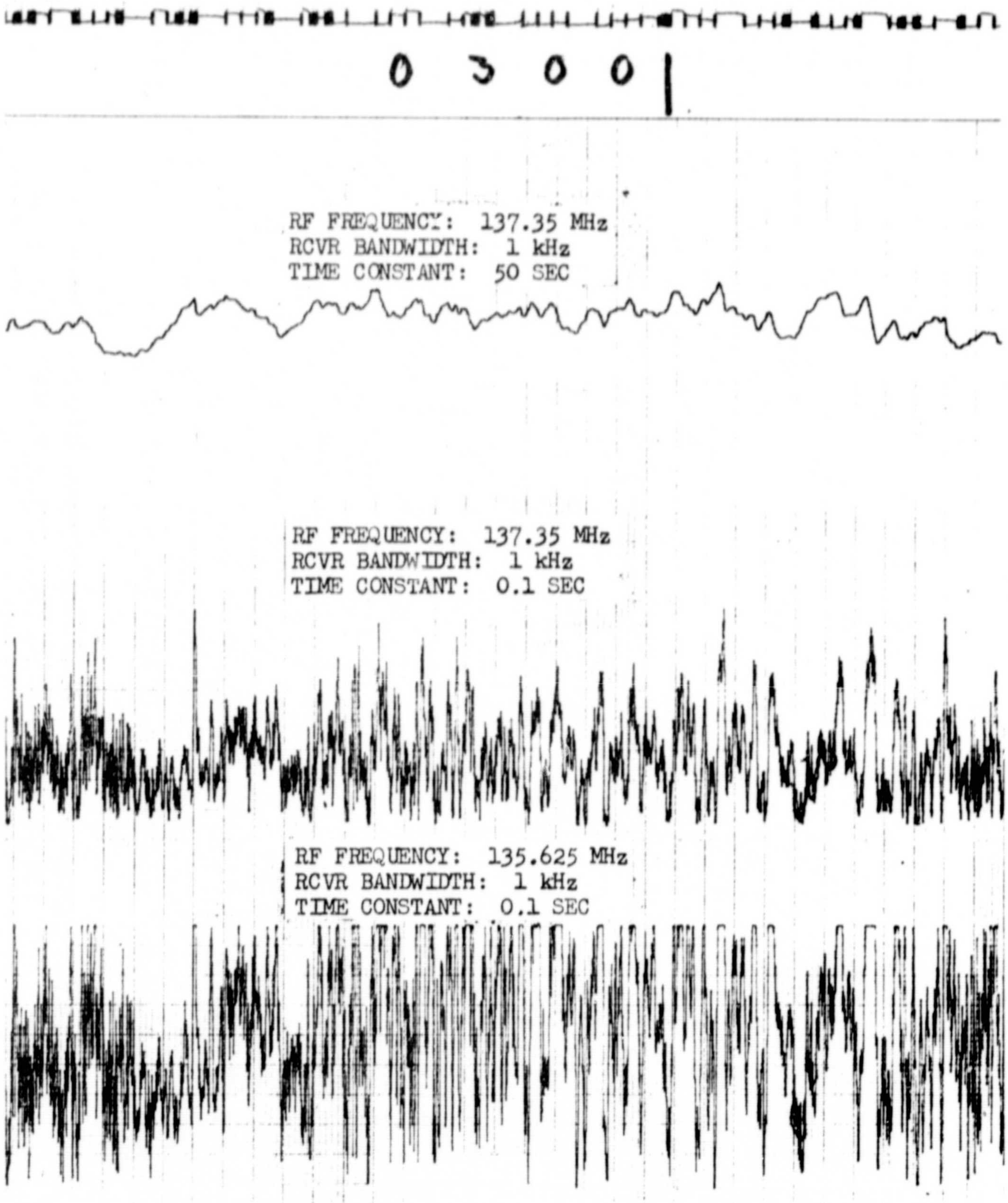


Figure 7. Segment of the Thule Record, November 11, 1969, ATS 3
(Chart Speed = 15 mm/minute)

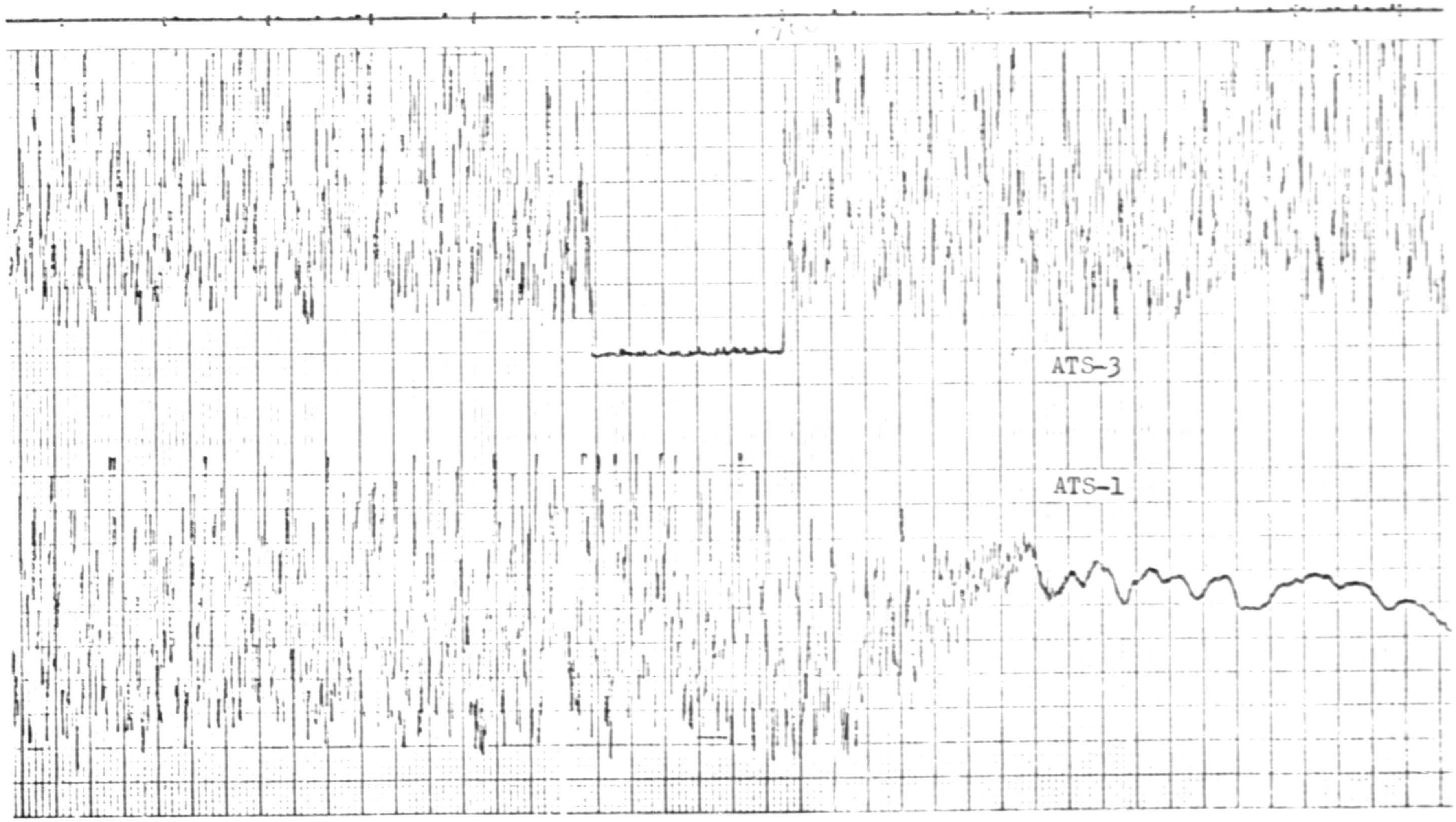


Figure 8. Segment of the Lima Record, Showing Onset of Scintillations on ATS-1, November 11, 1969, (Chart Speed = 15 mm/minute)

The next most serious condition occurs at midlatitude stations with low satellite-elevation angles; these stations commonly experience relatively long-period scintillations of 6-db peak-to-peak magnitude. Most of the midlatitude station records exhibited some scintillation, usually of minor magnitude but occasionally quite severe, such as that at Rosman on December 23.

Assessment of these data and comparison with previous data from the carrier Hornet show that variations in VHF propagation cannot logically be categorized with respect to station latitude alone, because satellite-elevation angle and coordinates of F-2 layer ray intersection are necessary parameters also. According to Figures 2 through 6, all the midlatitude stations with elevation angles above 6 degrees show essentially comparable activity. The data do not indicate that the amount of scintillation activity depends on position in the midlatitude region.

Although the method set forth in the objectives detected no traveling disturbances, others have investigated traveling disturbances and disturbance size.[2,3,4] The daily fluctuation manifested itself to the extent that the data from the geomagnetic equatorial stations substantiated previous observations of this effect (i.e., scintillation activity occurs typically before and after midnight at these stations, as it did on board the carrier Hornet last July).

Negative peaking noticed in the records from four of the stations listed earlier will probably be less detrimental to communications than variation of the signal in a more sinusoidal manner because, once the signal dips below the receiver threshold, it will remain there for less time than in sinusoidally varying cases.

The auroral data from Thule show more severe scintillations (Figures 2 and 7) than those from the geomagnetic equatorial stations. The record from Thule shows superimposed slow and rapid scintillations. This effect does not appear at Lima or Ghana, but appears occasionally at other stations such as Rosman and Mojave. When slow and rapid scintillations occur simultaneously, the effect is a higher magnitude variation of the signal.

Signal-level variations seen at the St. John's, Newfoundland, station peaked only on the negative side; this occurred during the December 16 test. In almost all other cases, the signal went alternately positive and then negative from the ambient received-signal level. The excursion magnitude from the St. John's data represents a fading condition, whereas in almost all other cases only half the excursion magnitude represents the magnitude of fade. This phenomenon is probably due to local causes, perhaps the equipment at this station.

RECOMMENDATIONS

Recommendations for future analysis and testing are:

- Future tests should include monitoring of the largest possible portion of the earth's ionosphere by assigning each participating station a particular satellite or satellites to monitor. The assignment would be contingent upon the coordinates of the F-2 layer ray crossing intersection. Table 3 gives F-2 layer coordinates for each participating station and each visible ATS satellite. This calculation will also serve to determine diurnal effects, as the necessary parameter is the condition of the ionosphere at the ray crossing.

- To assess satellite VHF communications with respect to earth-station location and to aid future designers of VHF communications systems, experimenters should calculate fade depth and duration statistics and make plots that will help determine for any given depth of fade (or enhancement), the distribution of fade durations, the total duration for a given time period, and the signal-level distribution. These statistics should be available both for the extreme latitudes and for a few midlatitude stations. (The sites should provide calibrations in 2-db increments.) The statistics derived from this recommendation will aid in assessing different modulation schemes.

- For the final report and any future analyses, the experimenters should categorize statistics according to F-2 layer ray-crossing coordinates, satellite-elevation angle, and sunspot number.

E. E. Metzger, NASA ground systems manager, intiated these propagation tests. G. Kuegler and J. McGillen of Westinghouse contributed suggestions and criticisms to this paper, and R. Rouiller of Westinghouse helped reduce the data.

Dr. J. Aarons and his staff of the Air Force Cambridge Research Laboratory helped to interpret the data and plan future analyses.

Station managers and crews, without whose assistance these tests could not have been performed, are:

Dr. A. daRosa	Stanford, California
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Dr. G. Hartman	Max Planck Institute, Germany
Zwi Houminier	Haifa, Israel
Tohru Ishida	Kashima, Japan
Dr. L. Kersley	Aberystwyth, Wales

Table 3
Subionospheric Ray-Crossing Coordinates

Location of Telescope	Intercept Latitude			Intercept Longitude			Telescope Elevation		
	ATS 1	ATS 3	ATS 5	ATS 1	ATS 3	ATS 5	ATS 1	ATS 3	ATS 5
Fort Myers, Fla.		24.71°			78.52°			41.05	
Fairbanks, Alaska	56.90°			148.08°			16.98		
Max Planck Inst.		46.18°			2.41°			12.40	
Univ. of Ghana		5.26°			3.46°			40.08	
G. E. (Schenectady)	37.63			98.14°			-0.63		
Aberystwyth, Wales		48.58°			15.29			20.18	
Kashima, Japan	32.62			206.91			10.46		
Quito, Ecuador		-0.58°			76.96	81.12		53.28	11.48
Winkfield, England		46.38°			16.88			18.52	
Thule AFB		61.90°			55.54			3.63	
Santiago, Chile		30.77°			49.60			40.75	
Canberra, Aust.	32.60			202.21			17.41		
Mojave, Calif.	32.66	31.81	32.77	120.83	101.30	115.78	35.58	6.04	50.07
Rosman, N. C.	31.79	32.53	32.63	97.27	78.71	85.02	7.52	34.29	45.38
Lima, Peru	-10.71	-11.02		91.45	74.80		5.19	53.80	
Kingston, Jamaica		16.82			76.30			51.31	
Inst. For Sat. Elec., Gy.		43.29		0.31				14.63	
Athens Univ., Greece		34.32			350.91			8.60	
Haifa, Israel		29.18			327.20			-0.39	
Cooby Creek, Aust.		25.20			201.64		22.76		
Witchita, Kansas	33.36	33.95		105.43	89.74		18.56	21.80	
Stanford, Calif.	34.49	33.31		125.80	101.73		37.88	1.23	
Grand Canaries		26.24			18.08			46.50	
St. John's, Nfld.		43.24			51.51			35.78	

Prof. J. Koster	Legon, Accra, Ghana
Dr. D. Matsoukas	Athens, Greece
E. Nielsen	Thule, Greenland
Dr. W. Goebel	DFVLR, Germany
Dr. A. Webster	Jamaica, West Indies
C. A. Petry	Annapolis, Maryland (Aeronautical Radio)
Boeing Aircraft	Wichita, Kansas

STADAN stations participating in the tests were:

Orroral, Australia	Mojave, California
Cooby Creek, Australia	Quito, Ecuador
Fairbanks, Alaska	Rosman, North Carolina
Fort Myers, Florida	Santiago, Chile
Grand Canary Island	St. John's, Newfoundland
Lima, Peru	Winkfield, England

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